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REVIEW OF THE HIGH ALTITUDE RESEARCH PROGRAM (HARP)

by

C. H. Murphy
G. V. Bull

July 1966

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U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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REVIEW OF THE HIGH ALTITUDE RESEARCH PROGRAM (HARP)

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RDT&E Project No. 1A011001B021

ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

REPORT NO. 1327

CHMurphy/GVBull/cr
Aberdeen Proving Ground, Md.
July 1966

REVIEW OF THE HIGH ALTITUDE RESEARCH PROGRA (HARP)

ABSTRACT

Project High Altitude Research Program (HARP) is directed toward the use of guns for scientific probing of the upper atmosphere. The attractive features of guns for this purpose are the basic economy of such a system and the high inherent accuracy of guns for placement at altitude as well as accuracy in ground impact. The basic liability for such an approach lies in the very high accelerations experienced by gun-launched payloads.

The guns used in Project HARP vary in size from 5-inch and 7-inch extended guns on mobile mounts to transportable fixed 16-inch guns. Altitude performance varies from 20 pound, 5-inch projectiles reaching 240,000 feet to 185-pound, 16-inch projectiles reaching 470,000 feet. Single and multiple stage rockets launched from the 16-inch gun have very promising predicted performance and are under development.

Scientific results to date are primarily wind profiles measured by radar chaff, aluminized balloons and parachutes, and tri-methyl-aluminum trails, although a number of successful 250 MHz and 1750 MHz telemetry flights have been made. Sun sensors, magnetometers, and temperature sensors have been flown and an electron density sensor was fired in early June. Development of other active sensors is continuing.

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1. INTRODUCTION

Project High Altitude Research Program (HARP) is a program of engineering and scientific research sponsored by the United States Army and the Canadian Department of Defence Production. The engineering objective of the program is the development of the gun launching system (guns, vehicles and payloads) to realize the maximum payload/mission potential. This ranges from the development of non-assisted, non-guided vehicles for probing to apogees in the order of 100 miles, to the development of multi-stage, gun-launched rockets with guidance and control in the upper stages such that in addition to specific re-entry placement capabilities, the system possesses significant orbital capability. The scientific portion of the program makes use of developed payload capability to conduct synoptic studies of the ionosphere as well as the usual meteorological measurements in the lower mesosphere.

The Army program is centered at the Ballistic Research Laboratories (BRL), Aberdeen Proving Ground, with participation of many other agencies in the various phases of the program. The joint Army/Canadian portion of the program is centered in the Space Research Institute of McGill University, and is monitored by the Joint International Steering Committee consisting of members of the Army Research Office, Army Materiel Command, Ballistic Research Laboratories, and the Canadian Department of Defence Production. The Space Research Institute of McGill University, working closely with the staff of the BRL, has developed and operates 16-inch gun systems in Barbados, W. I. and Highwater, Quebec, and has engineered the installation at the Yuma Proving Ground, Arizona. In addition, numerous vehicle systems have been or are under development along with appropriate payloads. The Institute organizes and coordinates the numerous 16-inch firing series which take place both for engineering test development purposes and for the gathering of scientific date.

2. MAJOR FEATURES OF THE GUN SYSTEM

The gun barrel, in addition to acting as a first stage re-usable booster, also acts as a guidance and control system. On emergence from the barrel, the vehicle is at a high velocity on a pre-determined flight path and is not significantly affected by surface winds. Thus, vehicle dispersion (in the case where there is no in-flight rocket-boost) can be closely controlled to both a predicted point in space, as well as impact into a relatively confined area. The gun-launch system from a dispersion point of view more closely approaches anti-aircraft gun fire than conventional rocket launches. In addition to the lower dispersion of a gun system compared to an unguided rocket, the re-usable booster characteristic of the gun barrel can lead to significant cost advantage over rocket systems.

The gun-launch technique takes on two different tasks in the HARP program. It may act simply as the first stage of a multi-stage rocket system with subsequent trajectory characteristics controlled by the performance and selected ignition times of the rocket stages, or may be the sole propulsive force applied to the vehicle. When it acts as the sole boosting stage, it then becomes necessary to achieve a ballistic coefficient larger than that of a conventional shell, and at the same time, double the muzzle velocity of conventional guns.[1,2*] The relation between launch ballistic coefficient, muzzle velocity and apogee is shown here in Figure 1. It may be noted from this figure that below a ballistic coefficient of 2000 pounds per square foot, apogee is controlled largely by the ballistic coefficient, while beyond this, apogee is controlled largely by muzzle velocity.

**Superscript numbers denote references which may be found on page 35.*

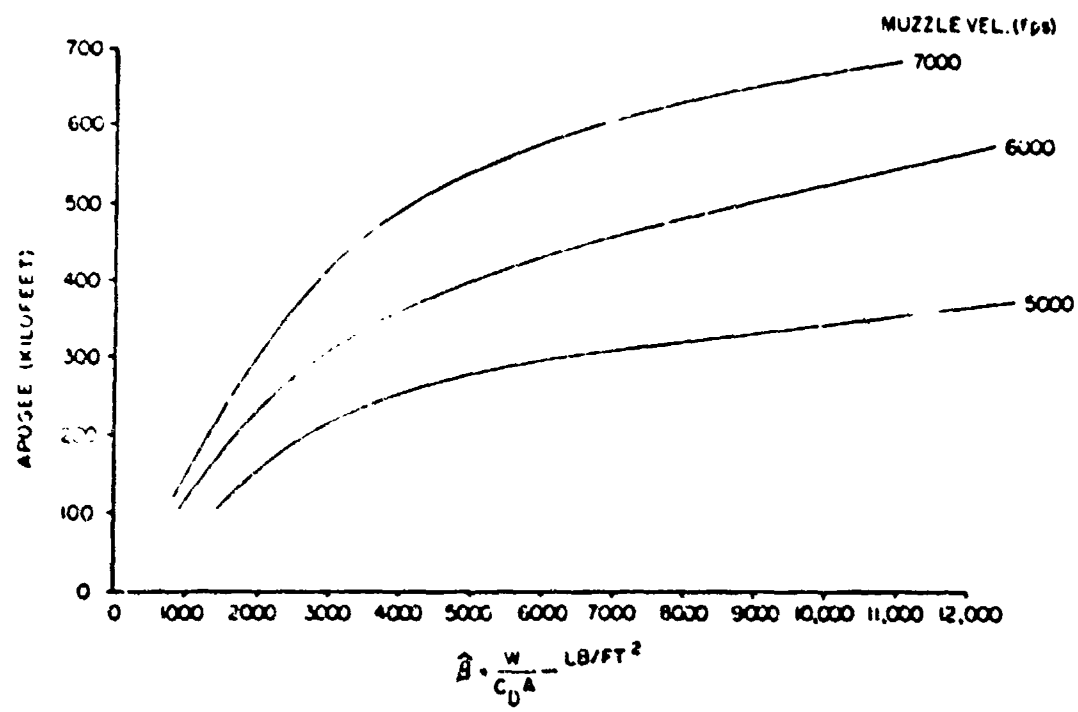


Fig. 1 APOGEE AS A FUNCTION OF BALLISTIC COEFFICIENT AND MUZZLE VELOCITY

Thus, in order to glide to apogees of interest, it is necessary to use sabot launched, sub-caliber vehicles (Figures 2-3). The vehicle launch ballistic coefficient can be kept large, while the all-up shot weight can be kept small. For example, the service 16-inch gun fires a 3000-pound shell at muzzle velocities of 2600 feet per second. The vehicle/sabot combination shown in Figure 2 has an overall weight of a nominal 400 pounds and has been launched at muzzle velocities of over 6000 feet per second. The pusher plate converts the gun pressure to a total thrust on the vehicle, while the petal arms keep the vehicle aligned during bore travel. A much lighter sabot system is shown in Figure 3; this supports the vehicle near its center of gravity, and lets the afterbody trail in the gun gases.

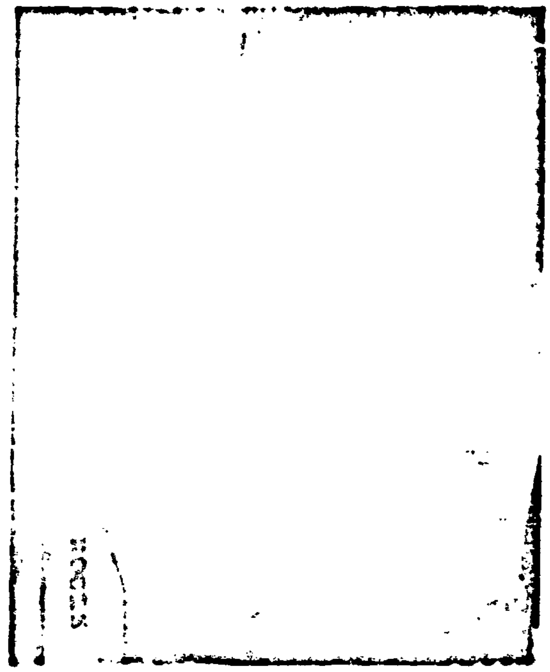


Fig. 2 16-Inch projectile with and without base pusher sabot.

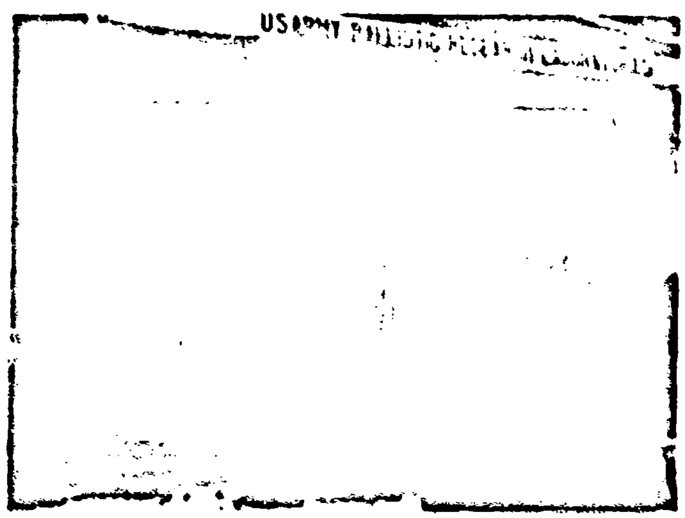


Fig. 3 5-inch and 7-inch projectiles with center sabots and 7-inch projectile without sabot.

In order to achieve optimum gun performance with these lightweight shots, it is necessary to increase the barrel length to between 75 to 100 calibers (approximately double the normal barrel length) and to tailor a suitable propellant web. The muzzle velocity is further increased as much as 200 feet per second by sealing the muzzle with a thin plastic sheet and evacuating the barrel of air. The current peak performance for HARP guns is given in the following table.

PEAK PERFORMANCE FOR HARP GUNS

Gun	Gun Length	In gun Weight	Flight Weight	Muzzle Velocity	Apogee
175 mm	34'	130 lbs	130 lbs	3150 ft/sec	81,000
5"	33'	25 lbs	20 lbs	5[illegible]00 ft/sec	240,000
7"	50'	75 lbs	60 lbs	5[illegible]00 ft/sec	300,000
7"	50'	47 lbs	27 lbs	[illegible]00 ft/sec	330,000
16"	119'	410 lbs	195 lbs	*6300 ft/sec	*468,000

All tubes are smoothbores except for the standard 175 mm. Usual payload weights are between 10% and 20% of flight weights.

*In November 19[illegible] an improved ignition system allowed the Yuma gun to achieve a velocity of 7[illegible] ft/sec and an apogee of 590,000 ft with this projectile.

Vehicles are subjected to acceleration loads that decrease in inverse ratio to the gun size (i.e., doubling the barrel diameter halves the peak g load). For the 7-inch gun, peak accelerations are in the 35,000 g range, for the light shot weights, while equivalent accelerations in the 16-inch gun are of the order of 15,000 g's. For the large rocket systems under development for the 16-inch gun, peak accelerations are in the 5,000 g range. A natural handicap of high-g gun launch is the special development of telemetry units and sophisticated sensors. The work to date indicates that this liability can be overcome in a number of applications.[3-5]

3. FIVE-INCH SYSTEM

3.1 Gun-Projectile Properties

The first HARP vertical firings were made in June 1961 from the Edgewood peninsula, 10 miles outside of the Baltimore city limit. These flights were made with a smoothbored 120 mm T-123 barrel and a center-sabot stabilized vehicle. The vehicles were constructed from excess parts of a defunct developmental missile. This non-optimum design reached an altitude of 130,000 feet and chaff was deployed.[6]

The next year, a 10-foot extension was added to the gun and an optimum design for the vehicle established. The present gun is shown on the right of Figure 4 and the 5-inch missile is the center missile in Figure 3. The 45-inch long missile (HARP 5.1) weighs 20 pounds with a 5-pound center sabot. The maximum body diameter is 2.6 inches and the fins are slightly smaller than the bore diameter. The center sabot consists of a four-piece aluminum section backed up by plastic quarters. The aluminum parts are locked to the missile by buttress threads and the plastic quarters seal the gun tube and supply most of the bore riding surface. The plastic part of the sabot is made slightly oversize and the projectile-sabot combination is rammed into the tube by a hydraulic jack.

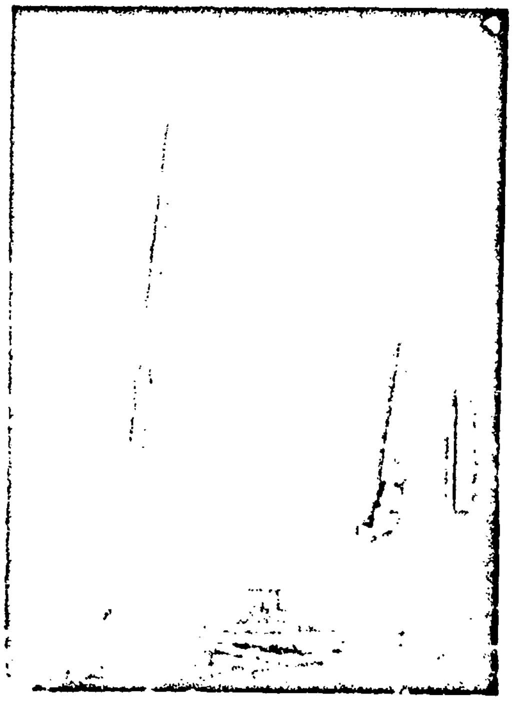
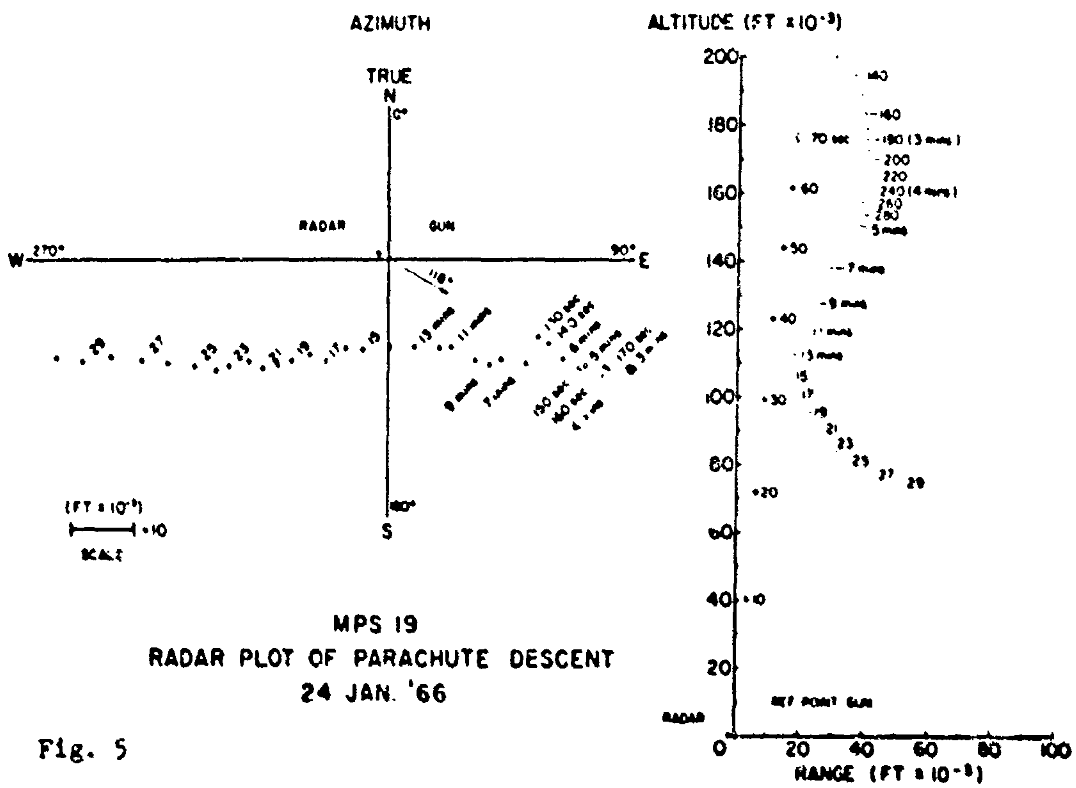


Fig. 4 5-inch and 7-inch extended smoothbore guns at Wallops Island, Va.

A 35-pound triple web mixture of M-17 is normally used and breech pressures range from 55,000 psi to 62,000 psi. Projectiles reach muzzle velocities of 5100-5200 ft/sec and apogees of 220-240,000 feet.[7,8] Early in the program, a significant number of apparently undamaged rounds flew to heights less than 100,000 feet, probably due to some aerodynamic difficulties. When the fins were beveled 3 degrees to induce spin, the missiles became most reliable and impact circle radii of less than one mile were routinely observed.

3.2 Payloads

The first payloads flown were radar chaff and aluminized parachutes. These are tracked by radar to give winds between 200,000 feet and 80,000 feet. Figure 5 is a sample radar plot for an aluminized six-foot square parachute flown over Barbados in January 1966.[25]



MPS 19
RADAR PLOT OF PARACHUTE DESCENT
24 JAN. '66

Fig. 5

An acoustic source payload[9] consisting of a 180-gm charge has been developed by the Atmospheric Sciences Laboratory at White Sands Missile Range and a high-g temperature sensor for use with 250 MHz transmitter and parachute deployment is under development. 1680 MHz transmitters are also under development. Over 75 observations of winds have been made by 5-inch HARP projectiles at various locations and these are being published in the Meteorological Rocket Network[10] (MRN) Data Reports.*

*The first report to contain this data is Volume XLVIII for August 1965.

In addition to meteorological measurements, telemetry payloads with accelerometers and sun sensors have been successfully flown to measure missile dynamics.[11]

3.3 Sites

The first vertical firings of the 5-inch HARP gun were made on the Edgewood peninsula of the Aberdeen Proving Ground. Most of the later developmental work has taken place at National Aeronautics and Space Administration (NASA) Wallops Island, Virginia facility where excellent radars are available which can skin track all projectiles to apogee. During the final stages of development, a second gun was located at White Sands Missile Range, New Mexico to initiate the MRN wind measurement program. When development of the vehicle and parachute ejection package was complete, two more guns were deployed to the HARP Barbados range and U.S. Army's test facility at Fort Greeley, Alaska. Thus three sites are now involved in a routine MRN network wind measurement program. Additional guns are planned for Johnson Island, Yuma Proving Ground, Arizona; and the HARP Highwater range. By May 1966, 162 flights were made at Wallops Island, 47 at White Sands Missile Range, 30 at Barbados, and 24 at Fort Greeley.

3.4 Balloon Altitude Measurements from Rifled Tubes

The primary meteorological data required by the field Army are current winds and temperatures up to 100,000 feet. Although balloons can obtain this data, balloons require moderate ground winds for launching, take over an hour to reach altitude, and can only sample points downwind of the launch point. As a result of the success of the 5-inch HARP gun, the use of presently available rifled tubes for meteorological sounding was suggested. A feasibility test of this concept was made with a standard 177 mm rifled tube mounted on an 8-inch mount[12] (Figure 6). A 3-foot square aluminized parachute with ejection fuze was placed in a standard shell and four shots fired at Wallops Island. Flights to between 79,000 feet and 81,000 feet were made and all parachutes were successfully tracked to provide wind data.

Fig. 6 175mm rifled tube set up for vertical fire.

4. SEVEN-INCH SYSTEM

4.1 Gun-Projectile Properties

The 7-inch system is essentially a scaled up version of the 5-inch system with three times the payload and an altitude capacity of 350,000 feet. The modern 175 mm M113 gun was smoothbored, extended by 26 feet,[13] and placed in a modified T-76 mount.* (The extended 7-inch gun is on the left in Figure 4.) The basic vehicle (HARP 7.1) is 64-inches long, has a 3.6-inch diameter and weighs 60 pounds. Seven-inch missiles with and without center sabots were shown in Figure 3.

The 7-inch vehicle plastic sabot is also made oversize and must be forced into the gun by a hydraulic jack. The charge is M17 bagged .114 web powder weighing up to 110 pounds. With this charge and a gun

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*Since there are only two T-76 mounts available, the 8-inch gun field mount has been modified for use with this system.[14]

pressure of 56,000 psi, a muzzle velocity of 5400 feet per second and apogee of 300,000 feet has been obtained for the 60-pound missile.

A smaller higher performance missile (HARP 7.2) is under development to reach 400,000 feet with a much smaller payload. This missile is 55-inches long, has a diameter of 3 inches and weighs 40 pounds. A preliminary version of this missile weighing 27 pounds has been placed at 330,000 feet.

4.2 Payloads

The usual wind sensor, chaff and aluminized parachutes have been successfully ejected from 7-inch missiles with particular interest associated with the ability of high altitude chaff to measure winds above 210,000 feet. The available payload volumes of over 125 cubic inches allows the use of chemical payloads of the type flown in Project Firefly.[15] A 10 to 12-pound mixture of cesium nitrate and high explosive is being developed for the generation of electrons at 330,000 feet. This payload has already been successfully deployed from a 16-inch missile and created an observable cloud of electrons over Barbados in late 1965.

The ability of this vehicle to reach through the D layer into the lower E layer of the ionosphere has lead to the development of a Langmuir probe with associated telemetry to make direct measurements of electron density. Early versions of this device have been successfully flown from both the 7-inch gun and the 16-inch gun.

4.3 Gun-boosted Rockets

The use of gun-boosted rockets should retain the accuracy and economy of a gun system and provide markedly increased payload and altitude capabilities. The accuracy advantage of a gun over an unguided rocket is based on the gun's high launch velocity and this advantage would also apply to a gun-boosted rocket. If we consider the gun-boosted rocket to be a two-stage system with a reusable first stage, a significant economy should be realizable. For these reasons, a full bore 7-inch rocket is under development as part of the HARP program.

The current concept for this development is a 125-pound full bore, fiber glass case, solid propellant rocket with pop-out fins which can be launched at muzzle velocities exceeding 4000 feet per second. This rocket should be able to exceed 500,000 feet with a 20-pound payload for a very modest cost. Full bore rocket grains in fiber glass cases have been successfully launched at 10,000 g's from a 6-inch gun. These are being scaled up to the 7-inch system and the pop-out fins are being flight tested. Vertical flights of this system are planned for late in 1966.

4.4 Sites

Although numerous horizontal tests of the 7-inch system and some vertical flights of high drag slugs have been made at Aberdeen Proving Ground, all vertical high performance flights of the 7-inch system have been made at NASA's Wallops Island facility. A second gun has been emplaced at White Sands Missile Range for tests in early summer, 1966, and guns are tentatively planned for Barbados and Johnson Island. Firm plans on additional sites depend on completion of a fully developed 7-inch system. By May 1966, thirty-four 7-inch vehicles had been fired at Wallops Island.

5. SIXTEEN-INCH SYSTEM

5.1 Gun-Projectile Properties

Late in 1962, McGill University obtained two U.S. Navy surplus 16-inch barrels and one complete mount. These barrels were smoothbored in the Spring of 1962 and transported to Barbados, West Indies in the summer by the U.S. Army Transportation Corps on the B.D.L. LTC John D. Page. These two 140-ton barrels with 90 tons of mount parts were landed on the beach at Foul Bay and railroaded overland 2.2 miles to the current launch site. In January 1963, the first vertical firings were made to proof test the gun installation. In June 1963, a 185-pound projectile was fired to 340,000 feet.[16] A 51-foot muzzle extension was attached

in March 1964 and a 185-pound projectile was fired to 430,000 feet.[17] With sabot and powder modifications and bore evacuation, the peak altitude was increased to 468,000 feet in November 1966.

The current Barbados 16-inch gun is shown in Figure 7. To stiffen this 119 foot 5-inch long barrel, 30 tons of 1-1/2-inch thick longitudinal steel gussets and 2-inch thick radial webs were welded in place. Eight tie rods were also added to reduce droop to acceptable limits in the elevated position. The stiffened extended barrel has a total weight of approximately 200 tons and can be elevated to 85 degrees in less than 8 minutes.

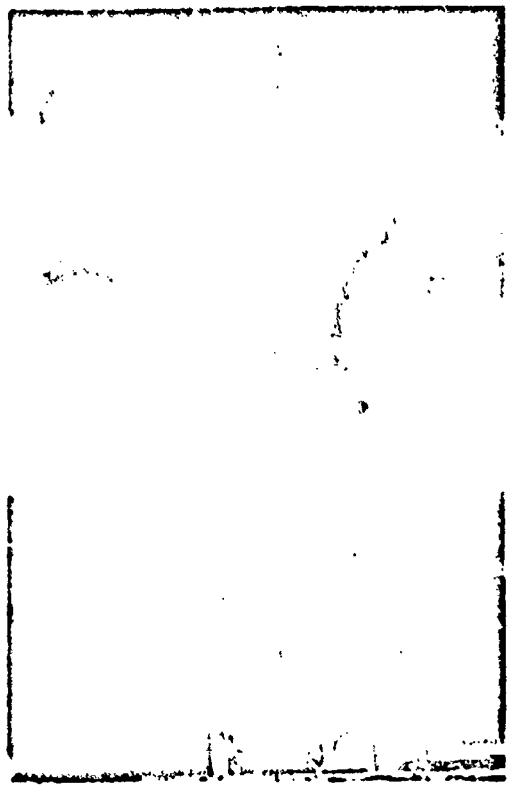


Fig. 7 16-inch extended smoothbore gun at Barbados, W.I.

The 16-inch projectile (Martlet 2C) is a 54-inch long fin-stabilized missile with a maximum body diameter of 5.4 inches and weighing 185 pounds. Its four fins have a total span of 11.4 inches and are canted 1/4 degree to produce a slow roll (shown in Figure 2). The missile is held in the gun by a 225-pound base pusher sabot consisting of an aluminum and steel base with four wooden 28-inch long arms. This sabot is also made oversize and must be forced into the gun by a hydraulic jack. A more efficient, but more sophisticated center sabot missile similar to the 5 and 7-inch missiles is under development as well as base pusher saboted vehicles with greater payload capacities.

The powder consists of bagged .225-inch web modified M8 propellant with a total weight of 780 pounds. A different web M8 powder has been used with a charge weight as high as 980 pounds. This charge is designed to yield 48,000 psi and a muzzle velocity in excess of 6100 feet per second. To increase the muzzle velocity further, the muzzle was sealed with a mylar sheet and the bore evacuated to a tenth of an atmosphere, thereby adding about 150 feet per second to the velocity and 20,000 feet to the apogee.

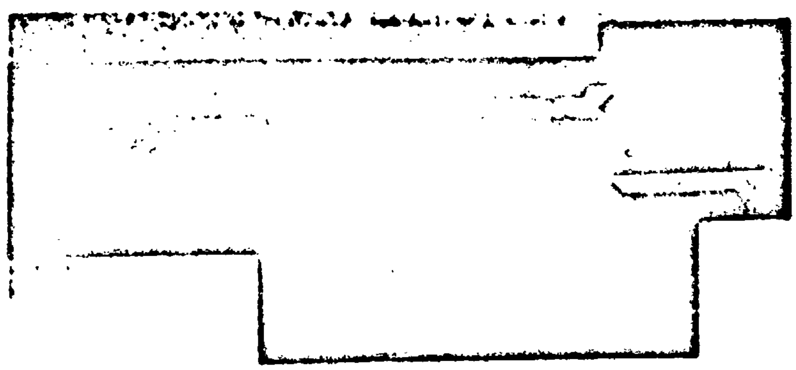
5.2 Payloads

The usual ejection payloads of chaff and aluminized parachutes have been flown from the 16-inch gun but all of these flights were limited to a maximum apogee of 250,000 to 300,000 feet for proper deployment, thus these payloads can, in most cases, be launched from smaller caliber guns. The placement of chemical payloads[15] above 330,000 feet is, however, a 16-inch gun mission. Liquid tri-methyl-aluminum has been used to produce luminous nighttime trails from 300,000 to 460,000 feet to measure ionospheric winds and a cesium compound has been exploded at 330,000 feet to produce an artificial cloud of electrons which was observed by a ground-based ionosonde for over 15 minutes.

Active payloads using both 250 MHz and 1750 MHz telemetry have been carried on a number of 16-inch flights. Onboard sensors have included magnetometers, sun sensors, pressure gages, and Langmuir probes. Although most of these devices have functioned successfully, they must still be considered as under development. Two Langmuir probe flights made direct measurements of electron densities in June 1965 and will be described in more detail later. 135 Martlet 2's have been fired in Barbados.

5.3 Gun-boosted Rocket Properties

The first gun-boosted rocket to be successfully flown from a HARP gun was a 5-inch aluminum body, fixed fin, subcaliber, solid propellant rocket fired from the Barbados 16-inch gun in September 1963, (Martlet 3A). This was followed in July 1964 by flights of a 9-inch steel body Martlet 3B at muzzle velocities up to 3200 feet per second and an acceleration level of 8000 g's. Figure 8 shows a Martlet 3B with a sun sensor slot and an antenna for 250 MHz telemetry. These tests[13] showed, however, that higher muzzle velocities and higher accelerations were not feasible for these unsupported center hole grains since the grains break up and ignition and explosion failure ensue. Hence, an engineering development was indicated.



MARTLET-3B

Fig. 8 16-inch subcaliber gun-boosted rocket.

Since July 1964, the gun was lengthened and a steel Martlet 3B was successfully fired[17] at 8000 g's and attained a muzzle velocity of 5200 feet per second. The low mass fraction associated with the metal bodies has been raised by introducing the use of fiber glass bodies. The first fiber glass versions were successfully fired at 3800 feet per second and improved versions are being developed. The peak performance of a developed subcaliber gun-boosted rocket is 800,000 feet with 35 pounds of payload. Eleven Martlet 3A's and twenty-five Martlet 3B's have been fired at Barbados. Ignition was attempted on all flights but the last 15 Martlet 3B's which were primarily structural tests.

The flight performance and economy of subcaliber rockets suffers severely in comparison with that of full-bore rockets which can carry 600 pounds to 400 miles at much lower cost per pound. The developmental problems of pop-out fins and 1000 to 1500 pound rocket motors seem to be well worth the effort, and the developmental effort is being shifted to work on the full-bore rocket. Several full-bore grains have been successfully launched horizontally at a muzzle velocity of 2200 feet per second and a number of pop-out fin tests have been made. Vertical flights of a 16-inch full-bore rocket are planned for late 1966.

5.4 Sites

In addition to the 119-foot long Barbados gun, a second 119-foot long gun is located at Yuma Proving Ground, Arizona (Figure 9), and a 104-foot long horizontal fire gun is located at Highwater, Quebec. The Yuma gun is limited by a 35-mile range restriction but possesses the important advantages of ground recovery and near geographical location to the West Coast rocket manufacturers. In addition to scientific soundings with Martlet 2's, this gun will be used for flight tests of attitude control and telemetry components requiring ground recovery and short duration rocket flights as well as other engineering tests appropriate to this location. The Highwater gun is used primarily for missile-sabot structural integrity tests, charge development, and rocket grain tests (see Section 7.2).

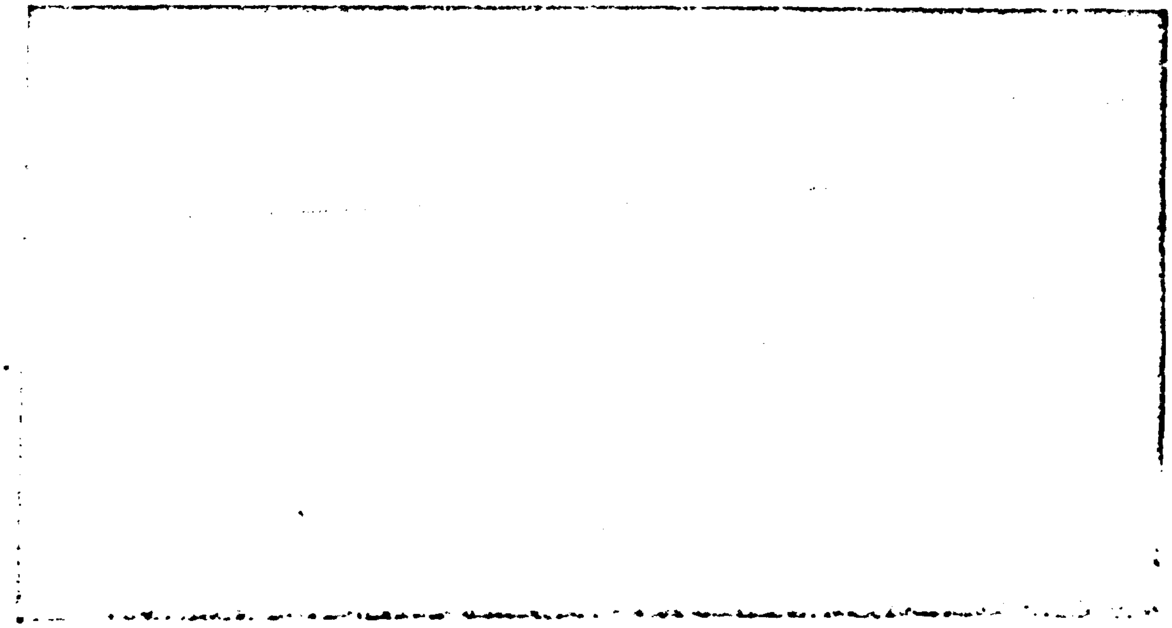


Fig. 9 16-inch extended smoothbore gun at Yuma Proving Ground, Arizona.

6. MULTI-STAGE GUN-BOOSTED ROCKETS

The full potential of the large caliber gun launch concept can only be realized by multi-stage gun-boosted rockets. Computer studies show that a three stage gun-boosted rocket can reach ICBM reentry velocities[19] or can generate sufficient velocity to establish an orbit.[20,21] In these studies, the three stage solid propellant rocket weighs 2000 pounds and is launched at 4500 feet per second by the extended 16-inch gun. Thus, the gun acts as a fairly large reusable first stage booster and, thereby, provides a low cost system for reentry studies or small satellite launches. The use of liquid propellant upper stages or larger caliber guns significantly increases payloads and reduces the cost per pound. A 32-inch gun, for example, will provide ten times the payload of the 16-inch gun for either mission.

Preliminary computer studies for the reentry mission have made use of two vacuum specific impulses, 250 second and 300 second, with corresponding payload weights of 50 pounds and 100 pounds. For both cases, stage mass fractions of 0.8 were assumed. Stage weights of

1200, 550, and 250 were assumed for the 50-pound payload and 1200, 500, and 300 for the 100-pound payload. A sample 50-pound payload trajectory calls for gun launch at 60 degrees elevation, first state ignition 35 seconds after launch with burnout velocity of 8260 feet per second, second stage ignition immediately following with burnout velocity of 14,300 feet per second, and a coast phase of 600 seconds before third stage ignition. With this program, the 50-pound payload is placed 1260 n.m. downrange with a velocity of 21,800 feet per second at 230,000 feet altitude and a reentry angle of -22 degrees. A possible orbit mission is shown in Figure 10.

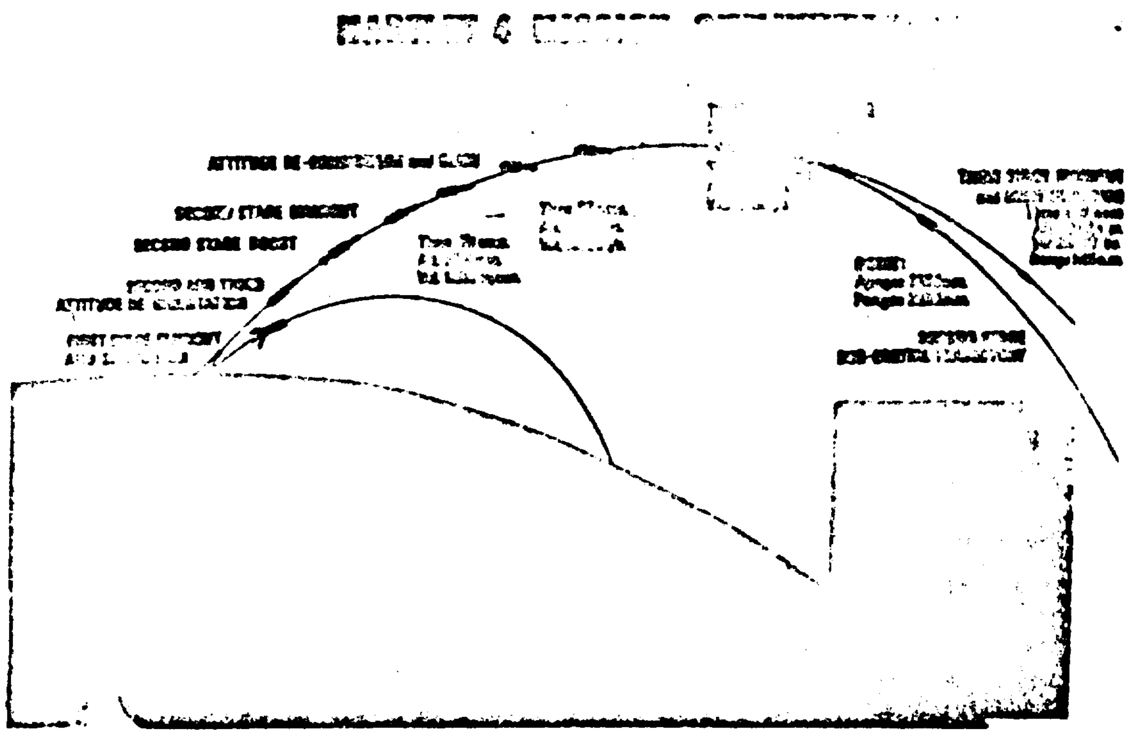


Fig. 10

The key engineering needs for either mission are development of a large first stage rocket and an acceleration resistant attitude control system. Since the full-bore 16-inch rocket has already been discussed, we will examine here the question of the attitude control system.

The primary components of attitude control systems are a spin rate sensor, a sun sensor, an infra-red horizon sensor, a computer and cold gas reaction jets (Figure 11). The combination of sun sensor and

horizon sensors can be used to determine the missile's attitude with respect to the sun and a normal to the earth.[22] The computer can then be used to properly position the upper stages during burning by means of the reaction jets. A breadboard version of this system has been assembled and successfully operated. All components have been launched at 10,000 g's from a 6-inch gun, recovered, and shown to be undamaged. First flight tests of the complete system are planned for late 1966.

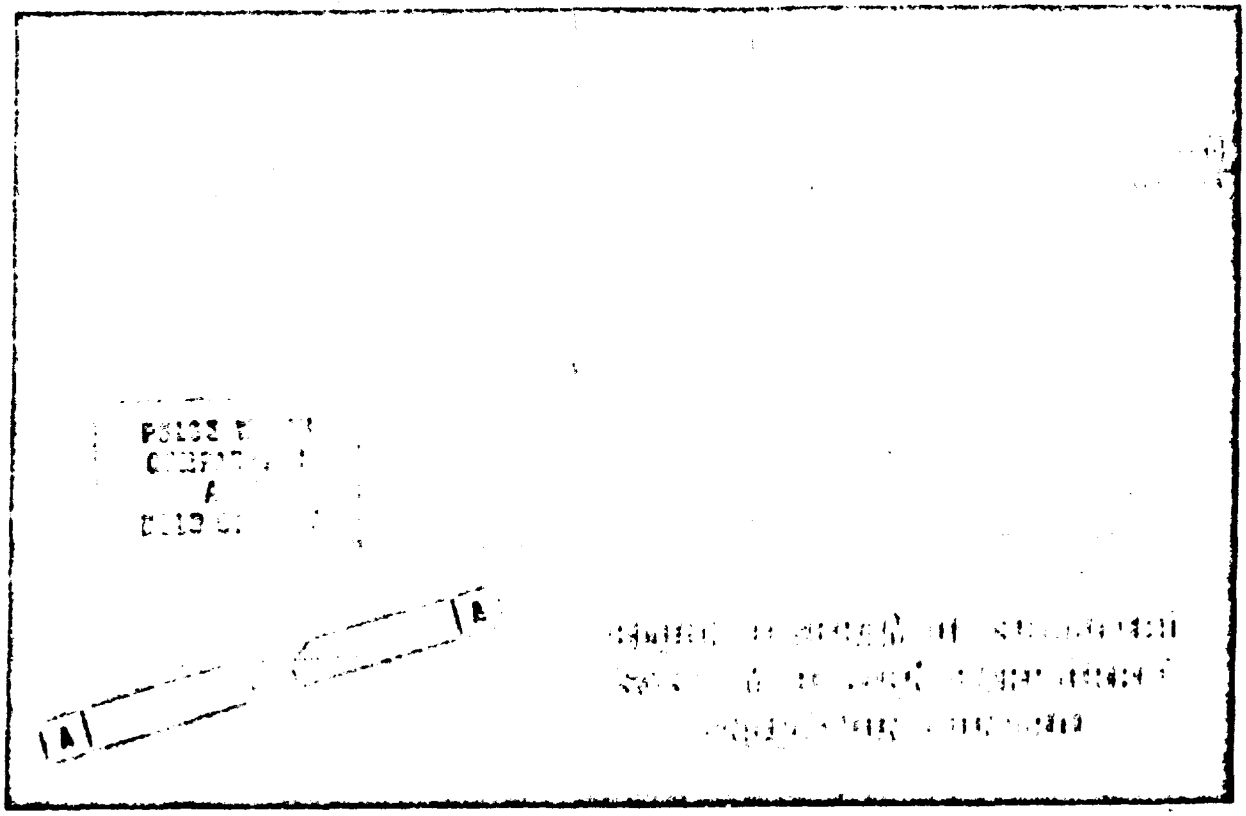


Fig. 11

7. HARP RANGES

7.1 Barbados Range (57.5° W; 13.1° N)

The Barbados range combines the advantage of a tropic location with the advantages of very long flights over water and nearness of various Eastern Test Range facilities. Its major disadvantage is remoteness from the industrial centers of North America.

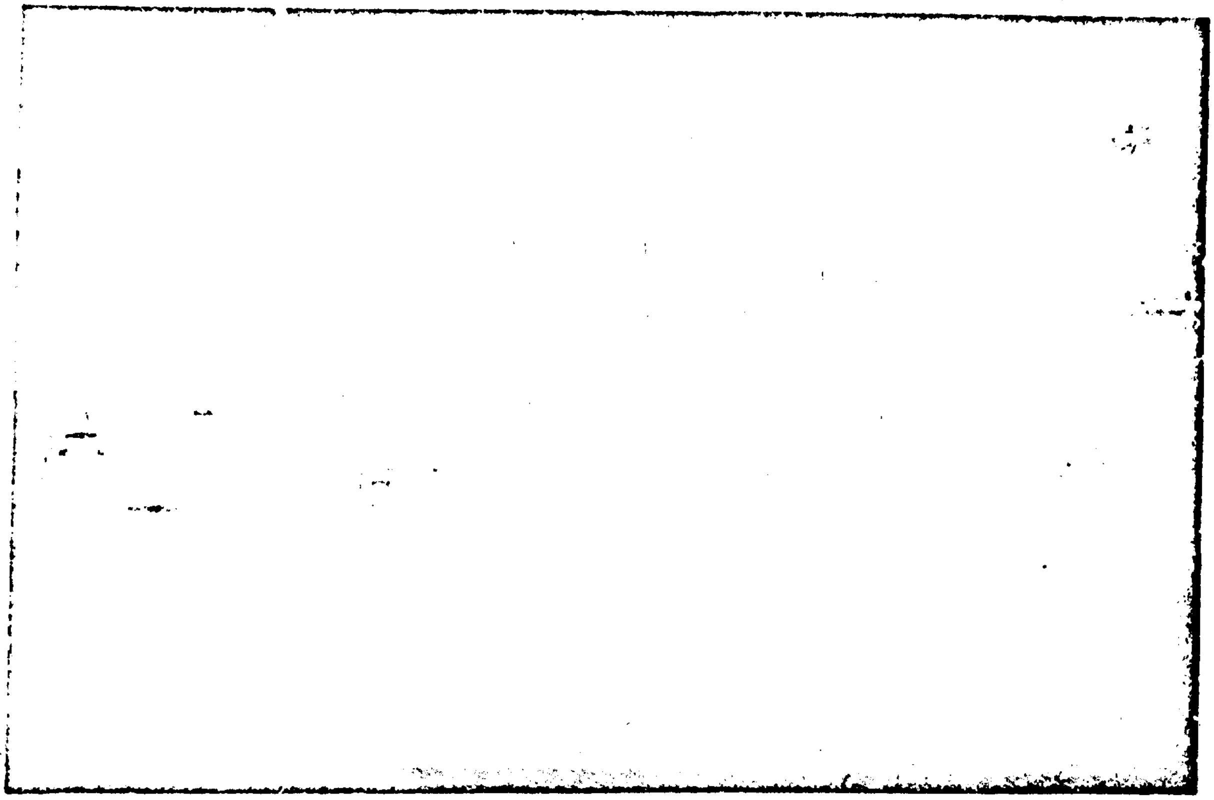


Fig. 12

The 16-inch gun* is located near the East end of the main runway for Seawell Airfield and fires on an asimuth of 119 degrees (Figure 12). On the cliff behind the gun, there are four camera locations (East Fastax Rear Smear, Side Smear, and West Fastax) and in front of the gun on a 50-foot tower a fifth location (Front Smear). Two thousand feet behind the gun are located the radars (M33 and MPS-19) and a telemetry receiving station (Figures 13 and 14). The MPS-19 can skin-track the Martlet 2 to 350,000 feet and the 5-inch projectile all the way, while the M33 is used for area surveillance. Almost 2 miles down the coast is the Range headquarters at Paragon House. This building houses the Launch Control Center, radio communications center, another telemetry receiving station, machine shop, and other supporting administrative activities. In view of the gun-runway location, all flights are cleared with the Seawell Control tower in addition to advising the Eastern Test Range (Cape Kennedy) as to firing schedule and results.

*The 5-inch gun is located directly in front of the 16-inch gun and fires on the same azimuth.

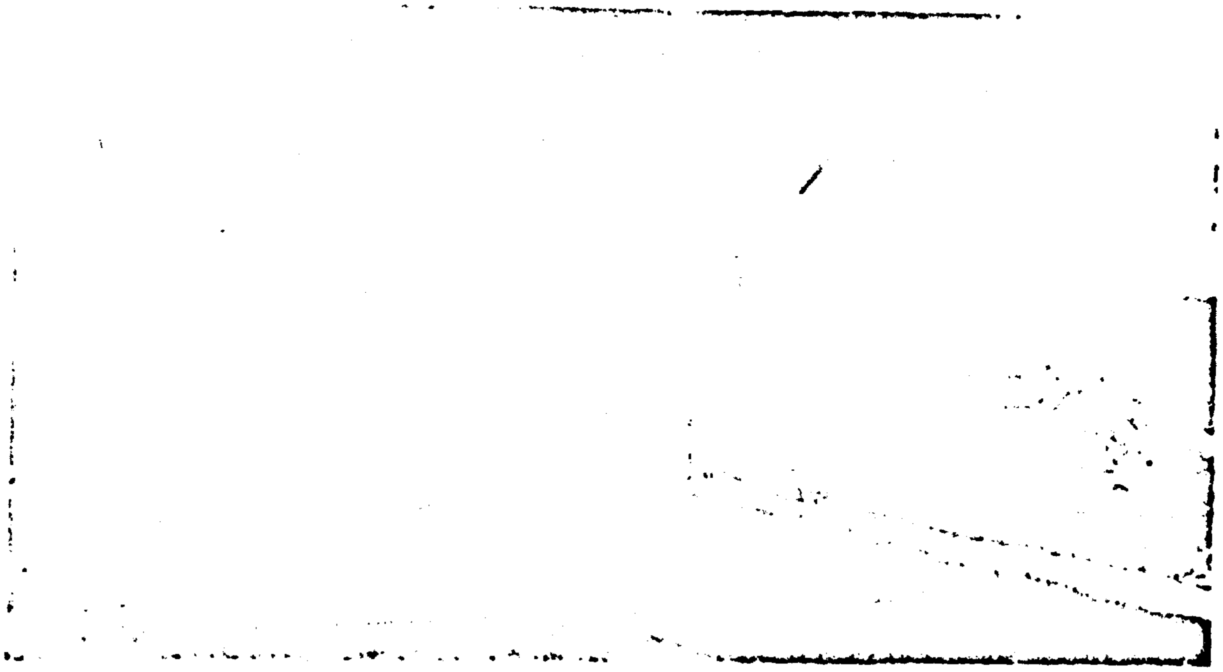


Fig. 13 HARP-Barbados MPS-19 radar.

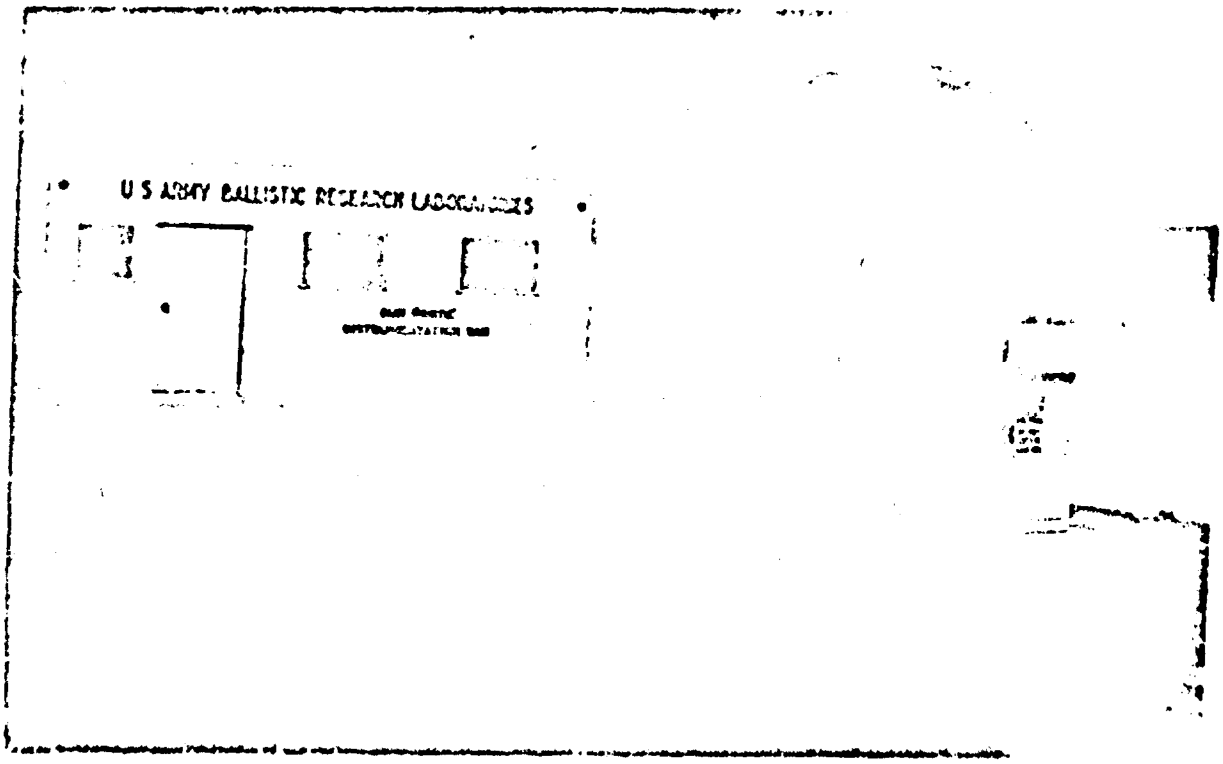


Fig. 14 1750 MHz receiving station and tracking antenna (modified GMD-1).

For proper coverage of the nighttime TMA trails, K-24 camera stations are operated on the islands of St. Vincent, Grenada, and Tobago, as well as on Barbados itself (Figure 15). All photographic stations are in radio communication with the HARP Launch Control Center. When they are available, additional radar support is supplied by the Eastern Test Range's radar on Trinidad as well as the ETR radar ship Twin Falls. The Trinidad radar has no difficulty in skin-tracking both the Martlet 2 and the 5-inch projectile from a range of over 200 miles.

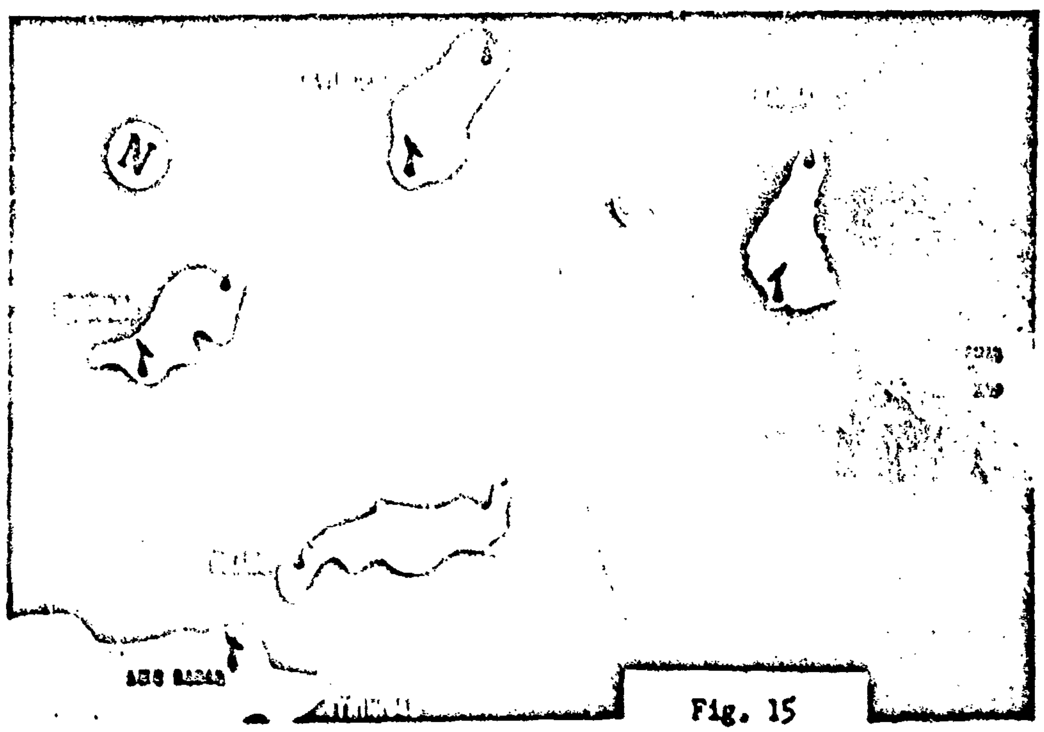


Fig. 15

7.2 Highwater Range (73° 31' W; 45° 2' N)

The Highwater Range is located in the Province of Quebec about 2 miles north of the Vermont border in the Green Mountains. It is in a natural valley which allows a restricted line of fire to the southwest (Figure 16). The range has been designed for large rocket flights with earth butts bulldozed at regular distances to destroy the vehicle should it deviate from the normal flight path which passes through a series of concrete tunnels. The natural valley also contributes to the overall safety of the range. Impact butts are located at 500 feet and 3000 feet (Stages 1 and 2) and a third butt can be located further down range to allow a flight of 10,000 feet (Stage 3). The particular impact point can be selected by adjusting the gun elevation.

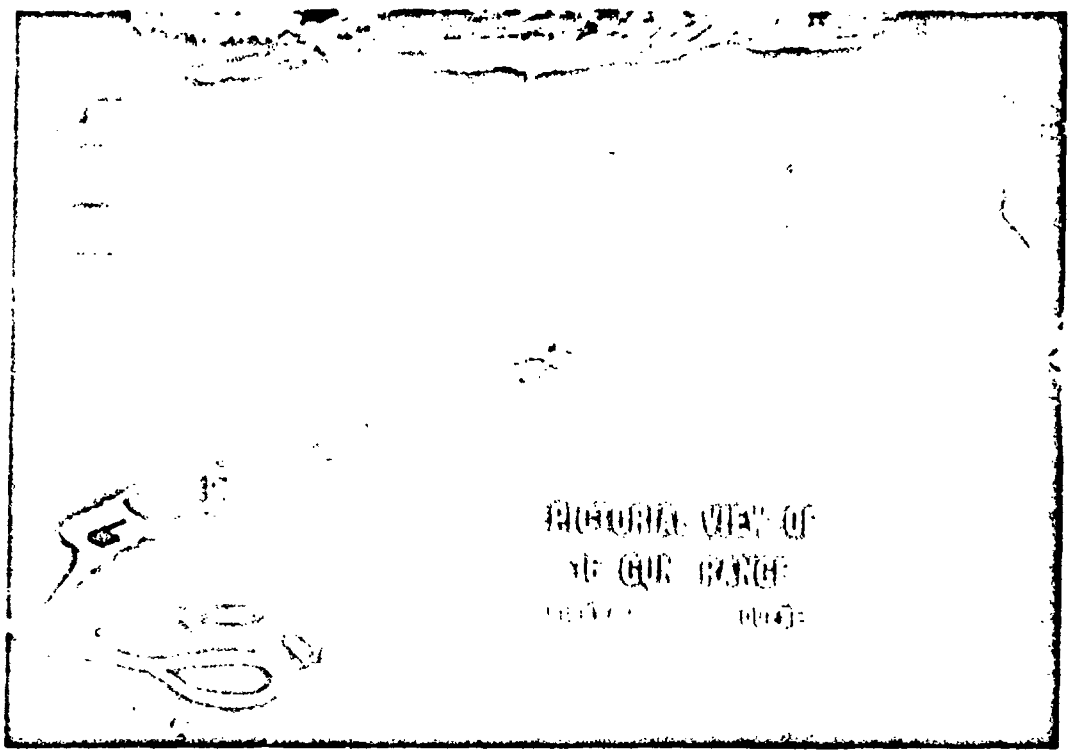


Fig. 16

The 16-inch gun* is elevated by means of a steel structure located near its center of gravity (Figure 17). A number of both full bore and subcaliber rockets have been successfully fired here with photographic coverage to determine structural integrity. In addition to structural tests of rocket grains and new sabot designs, interest is growing in using this gun to launch large configurations at hypersonic Mach numbers to measure various aerodynamic quantities such as heat transfer, surface pressures, and dynamic stability by means of onboard sensors and telemetry units.

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*A 6-inch gun is also located here for component tests and development of the 7-inch gun-boosted rocket.

Fig. 17 16-inch horizontal fire gun at Highwater, P.Q., Canada.

8. TWO HARP EXPERIMENTS

8.1 D-Layer Electron Density

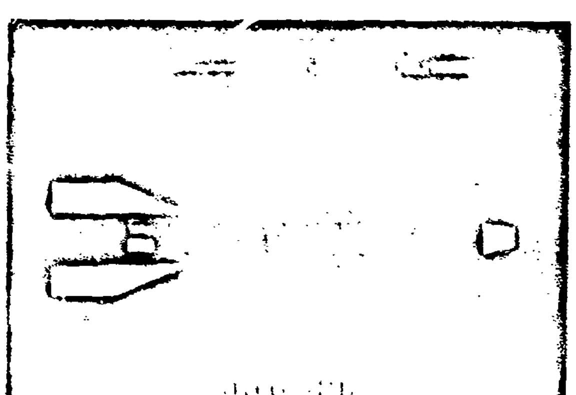

Fig. 18

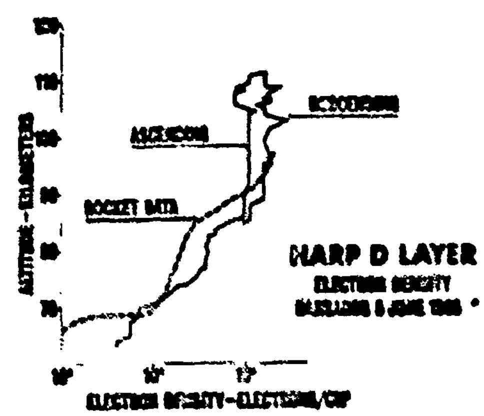

Fig. 19

The most sophisticated HARP experiment that has been carried out is the measurement of electron densities and temperatures by means of Langmuir probes.[23] The basic Langmuir payload has been hardened to 30,000 g's for launch from both the 7-inch gun as well as the 16-inch gun.

(Figure 18 shows the probe packaged for the Martlet 2.) The first successful flight of this probe was made in June of 1965 from the Barbados gun, using 1750 MHz telemetry (Figure 19). A number of additional flights of the Langmuir probe are planned for both guns in the summer of 1966.

8.2 Ionospheric Winds

The most detailed HARP experiment has been the measurement of ionospheric winds[24] by means of luminous TMA trails released from a Martlet 2 (Figure 20). The luminous trail which can be seen for over 200 miles and persists for over 15 minutes is photographed by the K-24 camera stations (Figure 21). The resulting photograph can be analyzed to yield wind profiles from 90 to 140 km (Figure 22). Records are concurrently

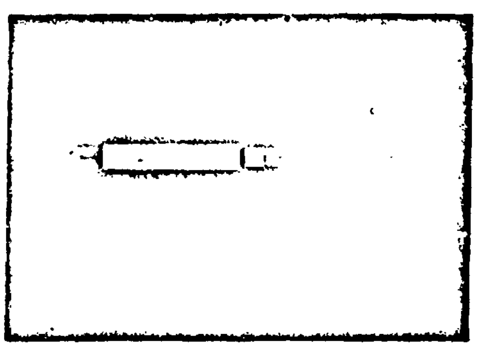

Fig. 20

Fig. 21 TMA trail over Barbados, W.I.

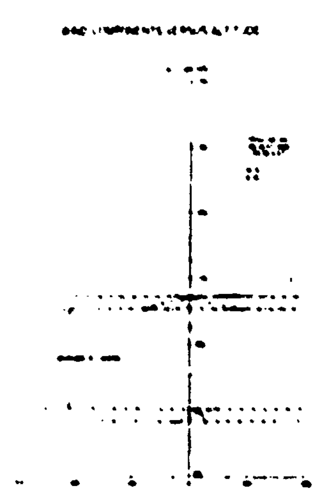

Fig. 22

taken by a ground-based ionosonde and correlations between location of sporadic E layers and high EW wind shear layers are studied. Fifty trails have been successfully photographed over Barbados and more are planned both at Barbados and at Yuma. With these synoptic studies in progress, an understanding of air circulation above 90 km and its effect on weather and communications seems to be realizable. The rapid variation of ionospheric wind throughout a night can be graphically shown by contour plots based on six HARP trails made in September 1965 (Figures 23 and 24).

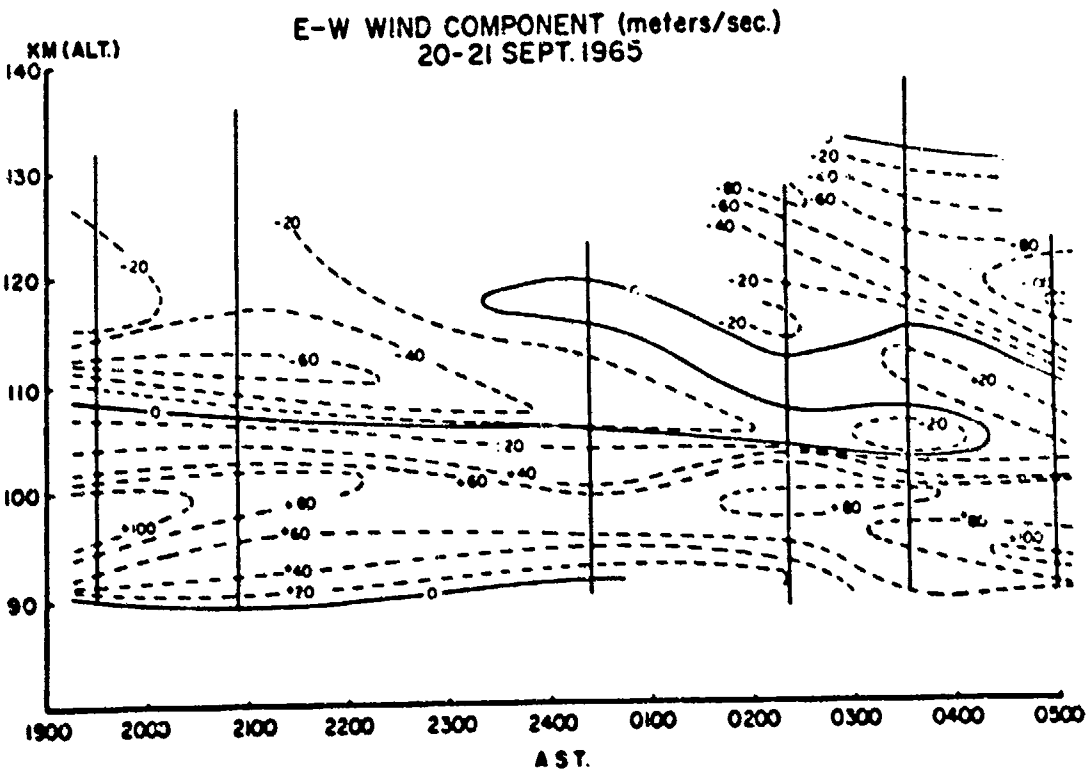

Fig. 23

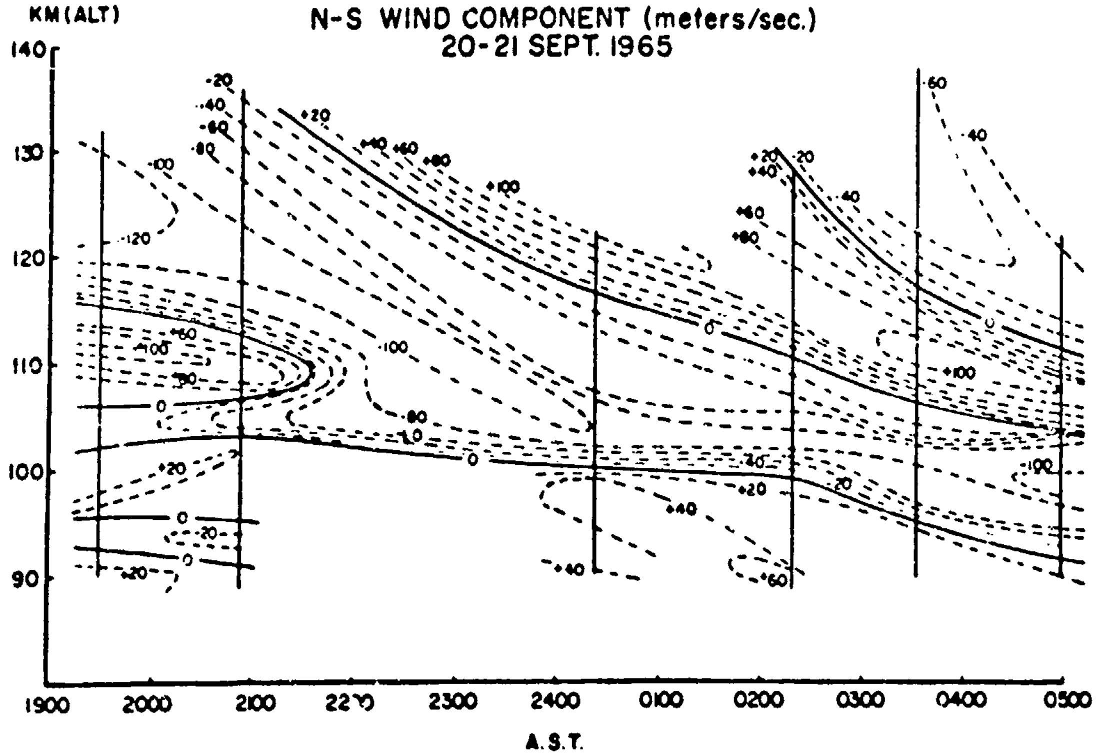

Fig. 24

9. SUMMARY

a. HARP gun-launched projectiles have reached an operational condition of routine synoptic sounding to 140 km at low unit costs.

b. HARP full-bore gun-launched rockets promise much greater performance but retain the ecomony of the gun system.

c. Full-bore multi-stage gun-boosted rockets have tremendous performance potentialities and the key problem areas of the rocket motor and attitude control units are under intensive study.

C. H. MURPHY G. V. BULL

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13 ABSTRACT

Project High Altitude Research Program (HARP) is directed toward the use of guns for scientific probing of the upper atmosphere. The attractive features of guns for this purpose are the basic economy of such a system and the high inherent accuracy of guns for placement at altitude as well as accuracy in ground impact. The basic liability for such an approach lies in the very high accelerations experienced by gun-launched payloads.

The guns used in Project HARP vary in size from 5-inch and 7-inch extended guns on mobile mounts to transportable fixed 16-inch guns. Altitude performance varies from 20 pound, 5-inch projectiles reaching 240,000 feet to 185 pound 16-inch projectiles reaching 470,000 feet. Single and multiple stage rockets launched from the 16-inch gun have very promising predicted performance and are under development.

Scientific results to date are primarily wind profiles measured by radar chaff, aluminized balloons and parachutes, and tri-methyl-aluminum trails, although a number of successful 250 MHz and 1750 MHz telemetry flights have been made. Sun sensors, magnetometers, and temperature sensors have been flown and an electron density sensor was fired in early June. Development of other active sensors is continuing.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Upper Atmosphere Probe						
Gun Launched Projectiles						
High Altitude Research						
Wind Measurements						

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